4.0 TMDL METHODOLOGY AND CALCULATION

4.1 Bacteria TMDLs

The following sections discuss the methods used for developing the April 2005 TMDLs and the 2006 CSO allocations. TMDLs, allocated loads, and percent reductions were developed for the stream segments listed on Pennsylvania's and Delaware's Section 303(d) lists of impaired waters for bacteria shown in Figure 4-1.

4.1.1 Methodology

The HSPF watershed models were used to calculate the baseline and allocation loads for fecal coliform bacteria for the TMDLs for the Pennsylvania listed waters. The models were calibrated over a four-year period (October 1, 1994 through October 1, 1998) to include both low and high streamflow. Following calibration, the same four-year period was used for the baseline and TMDL allocation simulations. For the baseline condition, all NPDES point sources were set to their permitted flow and bacteria levels (see Table 2-2). Estimates of septic system loads and bacteria accumulation and storage on different land uses in the watersheds were also incorporated into the models. A series of model runs were made in which the bacteria loads from failed septic systems and land sources were reduced until insteam water quality standards were met. A detailed description of the background, configuration, and calibration of the modeling system is provided in the modeling report (EPA, 2005).

Three models were used to determine *enterococcus* bacteria TMDLs for the Delaware listed waters: the HSPF watershed loading model, the XP-SWMM[1] CSO discharge model, and the EFDC[2] receiving water model. All three models were run for the October 1, 1994, through October 1, 1998, period and the baseline and allocation loads were determined. Since Pennsylvania and Maryland have the responsibility to meet the Delaware water quality standards at the state line, the HSPF models were used to calculate *enterococcus* bacteria loads at the Pennsylvania-Delaware state line for Brandywine Creek, White Clay Creek, Red Clay Creek, and Burroughs Run in the Red Clay Creek Watershed. A Maryland allocation was used to calculate *enterococcus* bacteria loads at the Maryland/Delaware state line for the Christina River.

The XP-SWMM model was used to calculate *enterococcus* loads from the CSO discharge points in the City of Wilmington. The daily time-series loads from the HSPF model and from the XP-SWMM model were then input to the EFDC[3] receiving water model to calculate *enterococcus* concentrations in the tidal waters of the Christina River, Brandywine Creek, and Little Mill Creek. More detailed descriptions of the calibration and application of these models are provided in the modeling report (EPA, 2005).

---

[1] The City of Wilmington provided the CSO discharges based on their XP-SWMM model runs.
[2] In reviewing the April 2005 TMDLs, it was discovered that Little Mill watershed was inadvertently left out the EDFC model.
[3] EDFC was used because HSPF is not applicable to tidal waters.

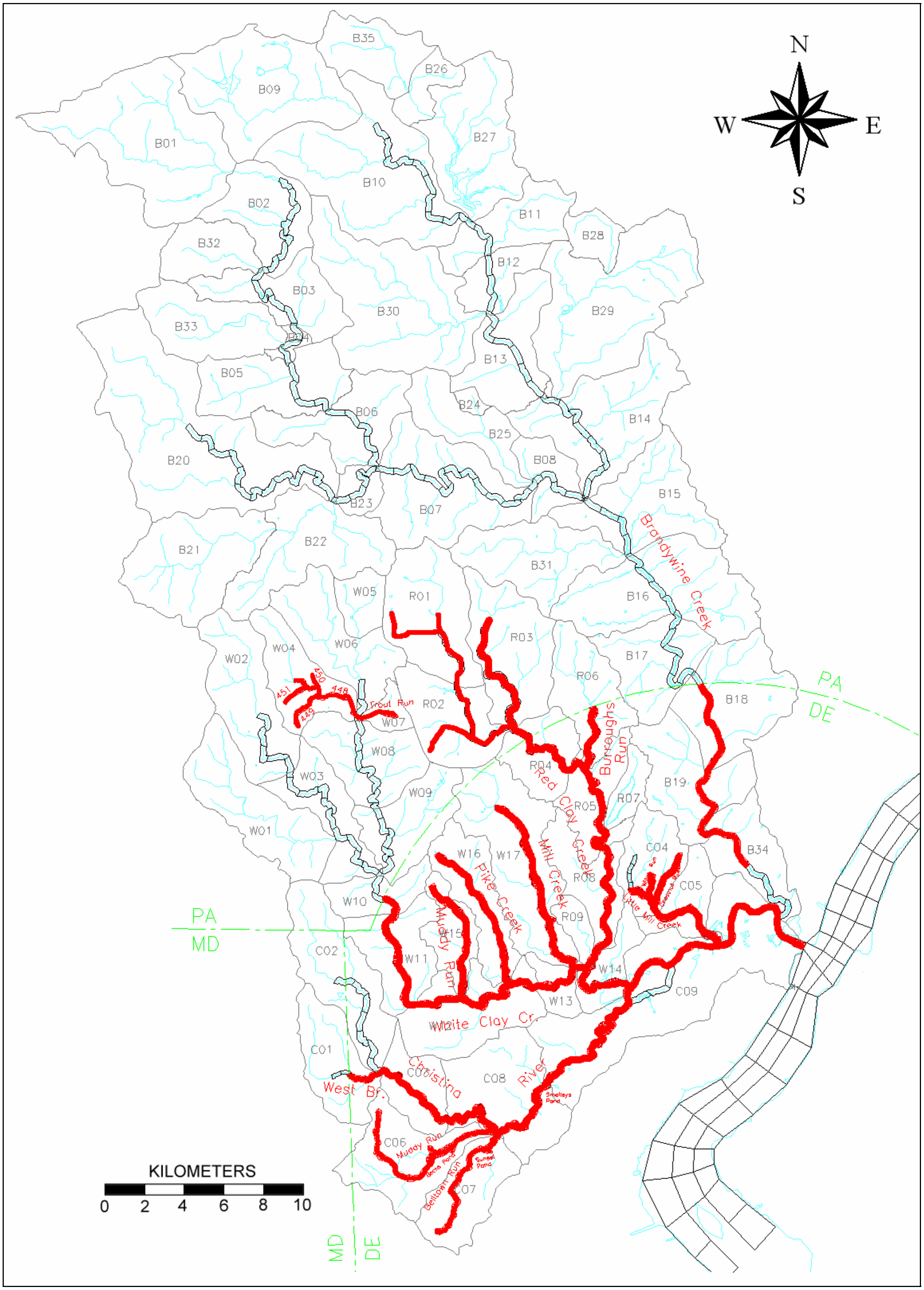

Figure 4-1. Locations of stream segments impaired by bacteria

4.1.2 TMDL Calculation

TMDLs were established for each fecal coliform bacteria-listed stream on Pennsylvania's Section 303(d) list. Each TMDL is the sum of the point source WLAs and the nonpoint source LAs, and a MOS. These TMDLs identify the sources of pollutants that cause or contribute to the impairment of the fecal coliform bacteria criteria and allocate appropriate loadings to the various sources. The basic equation used for TMDLs and allocations to sources is:

$$TMDL = \sum WLAs + \sum LAs + MOS$$

The WLA portion of this equation is the total loading assigned to point sources permitted under the NPDES program. The LA portion is the loading assigned to nonpoint sources. The MOS is the portion of loading reserved to account for any uncertainty in the data and the computational methodology used for the analysis. An explicit five percent MOS was used for this TMDL.

4.1.3 Wasteload Allocations

Federal regulations (40 CFR § 130.7) require TMDLs to include individual WLAs for each point source. None of the NPDES permitted dischargers, except as noted below, in the impaired subbasins were required to reduce their present NPDES permit limits of 200 cfu/100mL for fecal coliform bacteria or 100 cfu/100mL for *enterococcus* bacteria.

The City of Wilmington's CSOs are NPDES permitted discharges that currently have no permit limits. Future permits will contain permit limits and require reductions in loads discharged to the Christina River, Little Mill Creek, and Brandywine Creek.

EPA's storm water permitting regulations require municipalities to obtain permit coverage for all storm water discharges from municipal separate storm sewer systems (MS4) as described in Section 2.1.3. MS4s within the Christina River watershed receive allocations expressed as WLAs, enforceable through the NPDES permitting process.

Most of the townships/municipalities within the watershed have been designated by PADEP as covered under the NPDES Phase II Storm Water Regulations, and comprise the almost the entire watershed area. DNREC has issued MS4 permits covering all of New Castle County. MS4 bacteria baseline and allocation loadings were estimated based on drainage areas of each municipality, and the area-weighted WLAs were further allocated by the land use distribution of each municipality (see Appendix C, Tables C-1, C-2, C-3, C-4, C-8, C-9, C-10, C-11, C-12, and C13). MS4 permits issued to date require gathering information regarding the systems.

4.1.4 Load Allocations

According to Federal regulations (40 CFR § 130.2(g)), LAs are best estimates of the nonpoint source or background loading. These allocations may range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading.

As explained in Section 2.1.3, once a municipality delineates its MS4 sewershed area, the loads associated with nonpoint sources may be parsed out of the WLA and moved to the LA portion of the TMDL. Note that the total allocation will be unchanged. Example calculations are shown in Appendix E.

4.1.5 CSO Overflows

One of the key principles of the 1994 CSO Control Policy[4] is to provide levels of control that are presumed to meet appropriate health and environmental criteria. After the nine minimum controls, technology-based measures, were implemented, permittees were to develop long-term control plans. The permittees could use one of two approaches: (1) demonstrate its plan was adequate to meet the water quality-based requirements of the CWA or (2) implement a minimum level of treatment presumed to meet the water quality-based requirements. Wilmington selected the presumptive approach which requires capture for treatment of 85 percent of the combined sewage flows and limiting CSO discharges to less than an average of four to six events per year. Guidance[5] defines the required capture as:

> The elimination or the capture for treatment of no less than 85% by volume of the combined sewage collected in the CSS during precipitation events on a system-wide annual average basis.

The CSO loads are equal to the volume multiplied by the event mean concentration. See Appendix D for a discussion of the event mean concentration.

TMDLs and WLAs are generally expressed as loads, mass per unit time. When the TMDLs and WLAs are storm water related, as these TMDLs are, they are often expressed as average annual loads. This means that the analysis (or computer modeling) indicates that instream water quality standards are met each and every day (or as required by the water quality standards) over the predictive time-frame used when all loads are reduced as specified, and the loads entering the waterbody from each source are added together and divided by the number of years in the predictive time-frame used. Because Pennsylvania's bacteria criteria are based on the swimming/non-swimming seasons, the TMDLs and WLAs are average annual seasonal loads. TMDLs, WLAs, and LAs shown in following Tables 4-3 to 4-10 in average annual units are also shown in Appendix F in terms of units per day.

4.1.6 TMDL Results and Allocations

4.1.6.1 Fecal Coliform Bacteria

The fecal coliform bacteria impaired stream segments on Pennsylvania's Section 303(d) list are located in the East Branch White Clay Creek in subbasins W04 and W07 and the Red Clay Watershed in subbasins R01, R02, and R03. The HSPF models for the White Clay Creek and Red Clay Creek were run for the four-year period October 1, 1994, through October 1, 1998, for both the baseline (current) conditions and for the TMDL allocation conditions. Bacteria watershed loads were adjusted in the TMDL allocation scenario until the fecal coliform bacteria 30-day geometric mean water quality standards were achieved for both the swimming season (200 cfu/100mL from May 1 through September 30) and non-swimming season (2,000 cfu/100mL from October 1 to April 30). Watershed loads include domestic and wild animals, and failed septic systems.

The TMDLs and allocations are presented in Tables 4-1 through 4-3. A five percent MOS was used, which means the model instream fecal coliform bacteria concentrations were

---

[4] 59*FR*18688

[5] *Combined Sewer Overflows – Guidance For Long-Term Control Plan,* September 1995, EPA 832-B-95-005.

compared to 190 cfu/100mL and 1900 cfu/100mL instead of the water criteria of 200 cfu/100mL and 2000 cfu/100mL.

The non-MS4 point sources in both the Red Clay Creek and White Clay Creek where not reduced. See Table 2-2 for point source WLAs. The septic system loads were reduced by elimination of failed systems.

The baseline and TMDL allocation loads shown in Table 4-1 represent the average seasonal loads calculated from the HSPF model simulation during the period October 1, 1994, through October 1, 1998. In addition to the load allocations at the subbasin scale, the bacteria loads were allocated to the MS4 townships. Four municipalities including Avondale, London Grove, New Garden, and West Grove are located in subbasins W04 and W07. Four municipalities including East Marlborough Township, Kennett Square, Kennett Township and New Garden Townships are located in subbasins R01, R02, and R04. The TMDL allocations for the affected municipalities are shown in Table 4-2. Allocations for fecal coliform bacteria loads for septic systems in each of the impaired subbasins are provided in Table 4-3.

Table 4-1. Average annual seasonal fecal coliform bacteria TMDL allocations for the Christina River Basin

	Baseline Load (cfu/season)			TMDL Allocation (cfu/season)					Percent
Subbasin	PS	NPS	Total	WLA	MS4 WLA	LA	MOS	TMDL	Reduction
Swimming Season (May 1 - Sep 30)									
Red Clay (R01)	1.872E+12	2.914E+15	2.916E+15	8.734E+10	2.139E+14		1.126E+13	2.252E+14	92.28%
Red Clay (R02)	6.037E+12	1.319E+15	1.325E+15	1.274E+12	1.133E+14		6.031E+12	1.206E+14	90.90%
Red Clay (R03)	1.304E+12	1.435E+15	1.437E+15	1.738E+11	1.206E+14		6.359E+12	1.272E+14	91.15%
White Clay (W04)		1.726E+15	1.726E+15		1.040E+14		5.478E+12	1.095E+14	93.66%
White Clay (W07)	7.529E+10	3.140E+13	3.148E+13	7.529E+10	2.885E+12		1.557E+11	3.115E+12	90.10%
Non-swimming Season (Oct 1 - Apr 30)									
Red Clay (R01)	1.872E+12	6.404E+15	6.406E+15	8.734E+11	2.895E+15		1.524E+14	3.049E+15	52.40%
Red Clay (R02)	6.037E+12	3.406E+15	3.412E+15	1.274E+13	1.571E+15		8.338E+13	1.668E+15	51.12%
Red Clay (R03)	1.304E+12	3.704E+15	3.705E+15	1.738E+12	1.720E+15		9.062E+13	1.812E+15	51.08%
White Clay (W04)		2.499E+15	2.499E+15		2.370E+15		1.249E+14	2.495E+15	0.16%
White Clay (W07)	1.043E+11	6.899E+13	6.910E+13	7.529E+11	6.475E+13		3.450E+12	6.899E+13	0.15%

Table 4-2. Average annual seasonal fecal coliform TMDL allocations for MS4 municipalities

Town	Sub-Watershed	Swimming Season Baseline (cfu/season)	Swimming Season TMDL (cfu/season)	Percent Reduction
East Marlborough TWP	Red Clay	2.61E+15	2.06E+14	92.09%
Kennett Square Boro	Red Clay	2.35E+14	1.88E+13	91.98%
Kennett TWP	Red Clay	1.44E+15	1.24E+14	91.38%
New Garden TWP	Red Clay	1.12E+15	9.38E+13	91.60%
Avondale Boro	White Clay	3.81E+13	2.42E+12	93.64%
London Grove TWP	White Clay	1.54E+15	9.27E+13	93.99%
New Garden TWP	White Clay	3.00E+13	2.76E+12	90.82%
West Grove Boro	White Clay	8.48E+13	5.09E+12	93.99%

Town	Sub-Watershed	Non-Swimming Season Baseline (cfu /season)	Non-Swimming Season TMDL (cfu/season)	Percent Reduction
East Marlborough TWP	Red Clay	5.95E+15	2.85E+15	52.08%
Kennett Square Boro	Red Clay	5.45E+14	2.62E+14	51.95%
Kennett TWP	Red Clay	3.65E+15	1.78E+15	51.26%
New Garden TWP	Red Clay	2.76E+15	1.34E+15	51.52%
Avondale Boro	White Clay	5.83E+13	5.53E+13	5.06%
London Grove TWP	White Clay	2.23E+15	2.12E+15	5.04%
New Garden TWP	White Clay	6.59E+13	6.25E+13	5.15%
West Grove Boro	White Clay	1.23E+14	1.17E+14	5.04%

Table 4-3. Average annual seasonal septic system TMDL allocations of fecal coliform bacteria

Sub-Watershed	Estimated number of septic systems	Swimming Season Baseline (cfu/season)	Swimming Season TMDL (cfu/season)	Percent Reduction
Red Clay (R01)	553	6.13E+13	1.26E+11	99.79%
Red Clay (R02)	460	5.09E+13	1.05E+11	99.79%
Red Clay (R03)	779	8.63E+13	1.77E+11	99.79%
White Clay (W04)	224	2.48E+13	5.10E+10	99.79%
White Clay (W07)	42	4.69E+12	9.63E+09	99.79%
Sub-Watershed	**Estimated number of septic systems**	**Non Swimming Season Baseline (cfu/season)**	**Non Swimming Season TMDL (cfu/season)**	**Percent Reduction**
Red Clay (R01)	553	8.79E+13	1.75E+11	99.80%
Red Clay (R02)	460	7.31E+13	1.45E+11	99.80%
Red Clay (R03)	779	1.24E+14	2.46E+11	99.80%
White Clay (W04)	224	3.56E+13	7.06E+10	99.80%
White Clay (W07)	42	6.72E+12	1.33E+10	99.80%

4.1.6.2 *Enterococci* Bacteria

The locations of the stream segments listed as impaired for *enterococci* bacteria in Delaware are shown in Figure 4-1, and comprise most of the Christina River Basin within Delaware. Pennsylvania TMDL allocations for *enterococci* bacteria were determined at the PA-DE state line for Brandywine Creek, White Clay Creek, Red Clay Creek, and Burroughs Run and for Maryland at the MD-DE State line for the East and West Branches of the Christina River.

In Delaware, TMDL allocations were determined for each HSPF model subbasin to ensure protection of both the 30-day geometric mean criterion (100 cfu/100mL) also using a five percent MOS. The model run results were compared to a 30-day geometric mean of 95 cfu/100mL. All Delaware loads are average annual loads because Delaware does not have seasonal bacteria criteria.

In Pennsylvania, TMDL allocation results indicate that reductions in bacteria loading from land accumulation and from livestock's direct bacteria loading to streams on the order of 29 to 93 percent, respectively, are necessary to protect the water quality standards for *enterococci* bacteria at the PA-DE state line on Brandywine Creek, White Clay Creek, Red Clay Creek, and Burroughs Run. Approximately a 58 percent reduction is required at the MD-DE state line. Allocations are shown in Table 4-4.

The WLA portion of the TMDL allocation includes the contributions from CSO outfalls in the City of Wilmington (see Figure 4-2). The baseline loading for the CSO outfalls was determined using flow rates simulated by the XP-SWMM model and event mean concentrations (EMC) from CSO monitoring during storm events. Allocation model runs reduced the CSO loads by reducing the EMC but not the CSO volume except for CSOs 27, 28, and 29 on Little Mill Creek. For those three CSOs, the flows were routed through a storage tank to reduce the volume and load. The required total CSO load reduction from baseline conditions is approximately 68 percent as shown in Table 4-5. These reductions are based on the assumption that the Delaware River also meets applicable water quality criteria. See Appendix D for details.

The TMDL CSO load reductions shown in Appendix D, Table D-3, are one scenario of load reductions which, together with other sources' reductions, result in achieving instream water quality criteria throughout the length of the impaired waterbody. It should be noted that other scenarios are possible. In the future DNREC may allow an alternate CSO load reduction scenario, which also demonstrates that water quality standards are met throughout the length of the impaired waterbody.

In 2005 construction of a 2.3 million gallon (mgal) storage tank at Canby Park was completed to help capture overflows from CSOs 27, 28, and 29. Model runs indicate that the 2.3 mgal tank will reduce the average annual *enterococc*i load by 9.90E+13 cfu of the required 1.19E+14 cfu reduction specified by the TMDL. Thus, an additional annual reduction of 1.99E+13 cfu is needed to meet the TMDL in Little Mill Creek.

The non-MS4 point sources in Delaware where not reduced. See Table 2-2 for point source WLAs. Septic system loads were reduced by elimination of failed systems. In the Delaware subbasins, the overall reductions in *enterococci* bacteria from the baseline conditions range from about 29 percent to over 90 percent as shown in Table 4-6. The WLAs include non-MS4 point sources (Table 2-2) and CSO point sources.

Table 4-4. State line average annual allocations for Christina River Basin *enterococci* bacteria TMDL

Location	Baseline (cfu/yr)	Allocation (cfu/yr)	Reduction
Allocations at the Pennsylvania-Delaware State Line			
Brandywine Cr. (at PA-DE Line)	3.12E+15	2.01E+14	93.56%
White Clay Cr. (at PA-DE Line)	6.86E+14	2.06E+14	70.03%
Red Clay Cr. (at PA-DE Line)	2.58E+14	1.08E+14	58.05%
Burroughs Run (at PA-DE Line)	1.85E+13	1.30E+13	29.32%
Allocations at the Maryland-Delaware State Line			
Christina River (at MD-DE Line)	1.86E+13	7.73E+12	58.40%

Table 4-5. Summary of average annual CSO *enterococci* baseline loads and WLA TMDL

Location	CSO ID Numbers	Baseline (cfu/yr)	WLA (cfu/yr)	Reduction
Little Mill Creek (C05)	27, 28, 29	1.56E+14	3.69E+13	76.32%
Christina River (C09)	5, 6, 7, 9a, 9c, 10, 11, 12, 13, 14, 15, 16, 17, 30	3.54E+14	9.75E+13	72.47%
Brandywine Creek (B34)	3, 4a, 4b, 4c, 4d, 4e, 4f, 18, 19, 20, 21a, 21b, 21c, 22b, 22c, 23, 24, 25, 26, RR	6.89E+14	2.55E+14	63.07%
Total CSO Loads	-	1.20E+15	3.89E+14	67.57%

Table 4-6. Average annual allocations for Christina River Basin *enterococci* bacteria TMDL

Location	Baseline (cfu/yr)	WLA (cfu/yr)	LA (cfu/yr)	MOS (cfu/yr)	TMDL (cfu/yr)	Reduction
Brandywine Creek in Delaware						
Brandywine Cr. (B18)	1.11E+14	0.00E+00	5.55E+12	2.92E+11	5.85E+12	94.75%
Brandywine Cr. (B19)	5.57E+13	3.45E+10	6.31E+12	3.32E+11	6.68E+12	88.00%
White Clay Creek in Delaware						
White Clay Cr. (W11)	4.07E+13	0.00E+00	9.96E+12	5.24E+11	1.05E+13	74.23%
White Clay Cr. (W12)	1.49E+14	4.15E+10	1.79E+13	9.44E+11	1.89E+13	87.31%
White Clay Cr. (W13)	3.01E+13	0.00E+00	3.91E+12	2.06E+11	4.11E+12	86.34%
White Clay Cr. (W14)	3.82E+13	0.00E+00	3.99E+12	2.10E+11	4.20E+12	89.00%
White Clay Cr. (W15)	2.85E+13	0.00E+00	8.95E+12	4.71E+11	9.42E+12	66.90%
White Clay Cr. (W16)	1.02E+14	0.00E+00	1.32E+13	6.95E+11	1.39E+13	86.41%
White Clay Cr. (W17)	2.41E+14	0.00E+00	3.34E+13	1.76E+12	3.52E+13	85.43%
Red Clay Creek in Delaware						
Red Clay Cr. (R04)	5.89E+13	3.00E+12	8.52E+12	4.48E+11	1.20E+13	79.67%
Red Clay Cr. (R05)	2.25E+13	2.07E+10	7.90E+12	4.16E+11	8.34E+12	63.01%
Red Clay Cr. (R06)	1.51E+13	6.22E+08	1.01E+13	5.34E+11	1.07E+13	29.32%
Red Clay Cr. (R07)	6.05E+12	0.00E+00	1.74E+12	9.16E+10	1.83E+12	69.75%
Red Clay Cr. (R08)	7.61E+13	4.84E+11	7.83E+12	4.12E+11	8.73E+12	88.54%
Red Clay Cr. (R09)	2.88E+13	0.00E+00	2.89E+12	1.52E+11	3.04E+12	89.44%
Christina River and Tidal Brandywine Creek						
Christina River (C01)	3.51E+13	0.00E+00	1.27E+13	6.69E+11	1.34E+13	61. 90%
Christina River (C02)	8.16E+13	0.00E+00	2.47E+13	1.30E+12	2.60E+13	68.15%
Christina River (C03)	6.64E+13	0.00E+00	9.35E+12	4.92E+11	9.84E+12	85.18%
Christina River (C04)	8.69E+13	0.00E+00	6.73E+12	3.54E+11	7.09E+12	91.84%
Christina River (C05) *	2.21E+14	3.69E+13	4.84E+12	2.55E+11	4.20E+13	81.01%
Christina River (C06)	7.45E+13	0.00E+00	1.65E+13	8.70E+11	1.74E+13	76.66%
Christina River (C07)	7.16E+13	0.00E+00	1.08E+13	5.70E+11	1.14E+13	84.08%
Christina River (C08)	1.28E+14	0.00E+00	1.67E+13	8.79E+11	1.76E+13	86.29%
Christina River (C09) *	6.84E+14	9.75E+13	3.54E+13	1.87E+12	1.35E+14	80.30%
Tidal Brandywine Cr. (B34) *	8.23E+14	2.55E+14	1.33E+13	6.98E+11	2.68E+14	67.38%
Sunset Lake	6.39E+13	0.00E+00	1.41E+13	7.46E+11	1.49E+13	76.66%
Beck’s Pond	6.27E+13	0.00E+00	9.45E+12	4.99E+11	9.98E+12	84.08%
Smalley’s Pond	1.28E+14	0.00E+00	1.67E+13	8.79E+11	1.76E+13	86.29%
* CSO loads are included in the Baseline and WLA in these subbasins.						

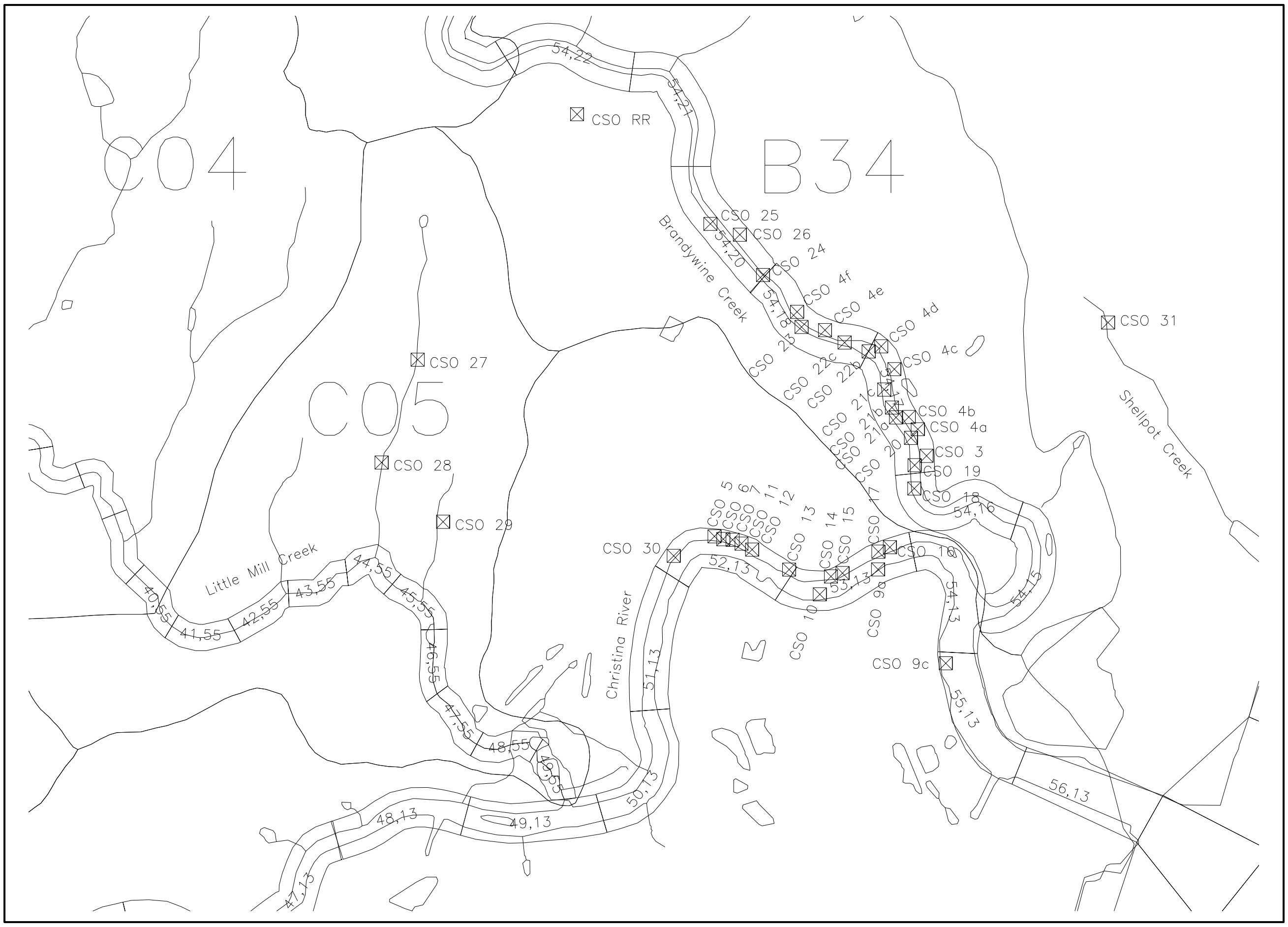

Figure 4-2. Location of CSO discharges in relation to EFDC model grid cells

4.1.7 Consideration of Critical Conditions

Federal Regulations (40 CFR § 130.7c(1)) require TMDLs to consider critical conditions for streamflow, loading, and water quality parameters. The intent of this requirement is to ensure protection of water quality in waterbodies during periods when they are most vulnerable. There may be multiple critical conditions depending on the different sources of bacteria. The four-year dynamic modeling addresses varying rainfall, flow, and seasonal variations of bacteria (EPA, 2001). The bacteria TMDLs for Christina River Basin adequately address critical conditions for flow and loading through analysis of a four-year hydrologic simulation that includes typical low and high flow variations in the basin.

The model calibration results for fecal coliform and *enterococci* bacteria show that the bacteria concentrations tend to be higher during the warm weather months. The bacteria concentrations appear to be correlated with cattle grazing behavior and storm events. The calibration results suggest that the highest bacteria concentration in terms of 30-day geometric mean may occur in warm weather following a storm event preceded by a long dry-weather period.

4.1.8 Consideration of Seasonal Variation

The critical conditions for bacteria, or any pollutant washed off the land surface by rainfall runoff, cannot be defined with a fixed flow rate. A long-term continuous simulation is one way to determine when the bacteria concentrations are highest. Therefore, the models were run for a four-year period (October 1, 1994, through October 1, 1998). This period is characterized by both extreme low flows during the summers of 1995 and 1997 as well as high-flow events during storms. This simulation period covered the range of typical critical hydrological conditions expected in the Christina River Basin.

4.1.9 Margin of Safety

The CWA and Federal regulations require TMDLs to include a MOS to take into account the relationship between effluent limitations and water quality. EPA guidance suggests two approaches to satisfy the MOS requirement. First, it can be met implicitly by using conservative model assumptions to develop the allocations. Alternately, it can be met explicitly by allocating a portion of the allowable load to the MOS. These TMDLs use an explicit five percent MOS.

4.2 Sediment TMDLs

The following sections discuss the methods used for TMDL development and the LAs, and percent reductions for the sediment-listed Pennsylvania waters. No stream segments are listed as impaired due to sediment in Delaware or Maryland. The stream segments listed for sediment impairment on Pennsylvania's 1996 Section 303(d) list are shown in Figure 4-3, and those on the 1998 Section 303(d) list are shown in Figure 4-4.

4.2.1 Methodology

Sediment and siltation problems tend to occur during wet weather periods when sediment washes off land surfaces and when high flows cause erosion of streambeds and stream banks. Sediment TMDL endpoints for the impaired reaches were developed using a reference watershed approach (see Section 3.2). After the impaired and reference watersheds were matched, the HSPF models were used to simulate the sediment loads from different sources for both the impaired and reference watersheds. The sediment loads calculated for the reference watersheds were used as endpoints for the impaired watersheds. A general description of the approach was previously shown in Figure 3-1.

The HSPF watershed models were used to calculate the TMDL sediment baseline and LAs for the Pennsylvania listed waters. The models were calibrated over a four-year period (October 1, 1994, through October 1, 1998) to include both low and high streamflow. Following calibration, the same four-year period was used for the baseline and TMDL allocation simulations. For the baseline condition, all NPDES point sources were set to their permitted flow and sediment (total suspended solids (TSS)) levels (see Table 2-2). No sediment loads were assigned to septic systems. Sediment yields from different land uses in the watersheds were incorporated into the models. A series of model runs were made in which the sediment loads from land sources were reduced until water quality standards were met. A detailed description of the background, configuration, and calibration of the modeling system is provided in the Modeling Report (EPA, 2005).

4.2.2 TMDL Calculation

TMDLs were established for the stream segments listed on Pennsylvania's Section 303(d) list. Each TMDL consists of point source WLAs, nonpoint source LAs, and a MOS. The basic equation used for TMDLs and allocations to sources is:

$$\text{TMDL} = \sum \text{WLAs} + \sum \text{LAs} + \text{MOS}$$

The WLA portion of this equation is the total loading assigned to point sources. The LA portion is the loading assigned to nonpoint sources. The MOS is the portion of loading reserved to account for any uncertainty in the data and the computational methodology used for the analysis. An explicit five percent MOS was used for this TMDL.

4.2.3 Waste Load Allocations

Federal regulations (40 CFR § 130.7) require TMDLs to include individual WLAs for each point source. None of the non-MS4 NPDES permitted dischargers in the impaired subbasins was required to reduce their present TSS NPDES permit limits shown in Table 2-2. Based on the available discharge monitoring reports the average discharge of sediment from such facilities in the watershed was usually well below the permitted TSS concentration.

EPA's storm water permitting regulations require municipalities to obtain permit coverage for all storm water discharges from municipal separate storm sewer systems (MS4) as described in Section 2.1.3. MS4s within the Christina River Watershed receive allocations expressed as WLAs, enforceable through the NPDES permitting process.

Sediment loadings were estimated based on drainage areas of each municipality, and the area-weighted WLAs were further allocated by the land use distribution of each municipality (see Appendix C, Tables C-5, 6, and 7).

4.2.4 Load Allocations

According to Federal regulations (40 CFR § 130.2(g)), LAs are best estimates of the nonpoint source and background loading. These allocations may range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint sources should be distinguished (EPA, 2001). Model output for the impaired subbasins includes sediment loads from each of the contributing land uses as well as a total sediment load from streambed erosion.

As explained in Section 4.1.3, once a municipality delineates its MS4 area, the sediment loads associated with nonpoint sources may be parsed out of the WLA and moved under the LA portion of the TMDL. Note that the total LA will be unchanged. See Appendix E, Storm Water Permits, Sample Calculations.

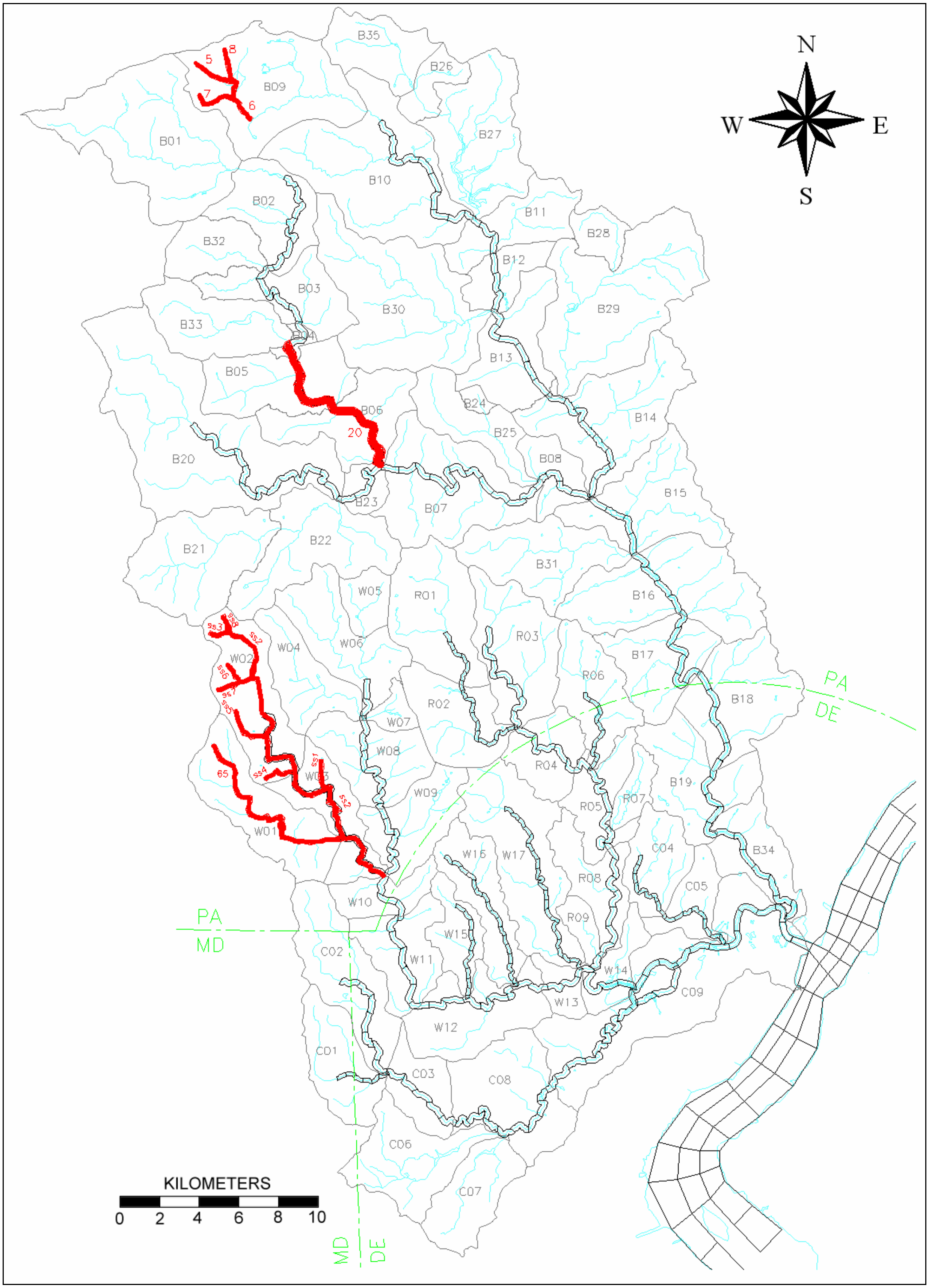

Figure 4-3. Stream segments impaired by sediment on Pennsylvania 1996 Section 303(d) list

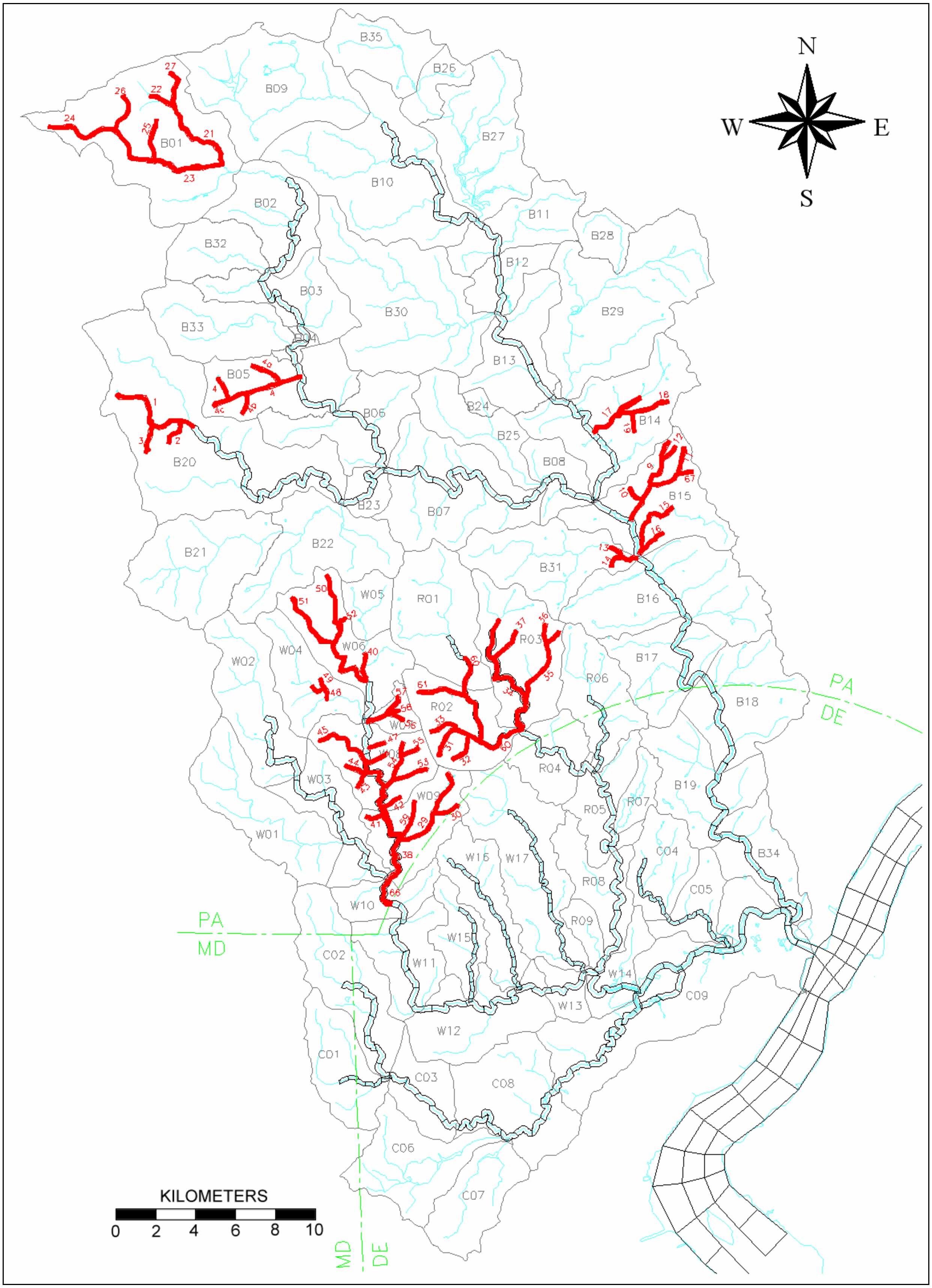

Figure 4-4. Stream segments impaired by sediment on Pennsylvania 1998 Section 303(d) list

4.2.5 TMDL Results and Allocations

The TMDL allocations for sediment in the Christina River Basin are presented in Table 4-7. The NPDES permitted point sources shown in Table 2-2 are summed by subbasin in Table 4-7. The TMDL allocations for the MS4 municipalities in Brandywine Creek, Red Clay Creek, and White Clay Creek Watersheds are listed in Table 4-8, 4-9, and 4-10, respectively.

Table 4-7. Average annual[6] allocations for Christina River Basin sediment TMDL

Subbasin	Baseline Load (ton/yr)			TMDL Allocation (ton/yr)					Percent Reduction
	PS	NPS	Total	WLA	MS4 WLA	LA	MOS	TMDL	
Brandywine Creek									
B01	29.80	776.03	805.83	29.80	414.16	84.82	27.83	556.61	30.9%
B04	0.00	42.63	42.63	0.00	21.77	-	1.15	22.92	46.2%
B05	246.02	1278.65	1524.67	246.02	421.74	-	35.15	702.91	53.9%
B06	0.08	340.20	340.28	0.08	219.34		11.55	230.97	32.1%
B09	0.04	498.86	498.89	0.04	180.75	218.75	21.03	420.57	15.7%
B14	79.81	1637.50	1717.31	79.81	631.82	-	37.45	749.08	56.4%
B15	9.19	1214.60	1223.79	9.19	509.37	-	27.29	545.85	55.4%
B20	1.68	1119.58	1121.26	1.68	645.94	49.03	36.67	733.31	34.6%
B31	0.04	1189.38	1189.42	0.04	452.25	-	23.80	476.09	60.0%
White Clay Creek									
W01	0.30	5353.56	5353.87	0.30	2940.17	-	154.76	3095.23	42.2%
W02	11.42	7999.18	8010.60	11.42	2283.47	449.21	144.43	2888.53	63.9%
W03	0.00	3168.54	3168.54	0.00	1825.04	-	96.05	1921.10	39.4%
W04	0.00	5187.94	5187.94	0.00	1722.66	58.57	94.49	1875.72	63.8%
W06	2.83	8114.08	8116.92	2.83	1795.34	667.6	129.78	2595.55	68.0%
W07	2.97	1414.61	1417.58	2.97	393.60	-	20.87	417.44	70.6%
W08	2.19	4606.80	4609.00	2.19	2146.83	-	113.11	2262.13	50.9%
W09	0.05	2808.89	2808.95	0.05	1968.74	-	103.62	2072.42	26.2%
Red Clay Creek									
R01	8.45	8424.04	8432.49	8.45	3500.39	329.31	201.96	4040.11	52.1%
R02	50.26	6252.12	6302.38	50.26	2805.45	-	150.30	3006.01	52.3%
R03	6.85	7218.12	7224.97	6.85	3761.33	-	198.33	3966.51	45.1%

The TMDLs in Table 4-7 were not revised. However, where a subbasin is not completely within a MS4 jurisdiction, the TMDL is divided into the MS4 WLA and LA.

[6] See Appendix F for loads in terms of units per day.

Table 4-8. Average annual sediment allocations for towns in Brandywine Creek Watershed

Township	Baseline (ton/yr)	TMDL (ton/yr)	Percent Reduction
BIRMINGHAM TWP	310.81	130.35	58.06%
COATESVILLE CITY	231.29	79.76	65.52%
EAST BRADFORD TWP	1185.00	467.17	60.58%
EAST FALLOWFIELD TWP	803.23	426.42	46.91%
EAST MARLBOROUGH TWP	366.70	139.44	61.98%
HIGHLAND TWP	384.80	238.86	37.93%
HONEY BROOK BORO	20.58	13.23	35.70%
HONEY BROOK TWP	813.84	558.76	31.34%
MODENA BORO	27.96	12.46	55.43%
NEWLIN TWP	144.18	59.59	58.67%
PARKESBURG BORO	52.11	32.35	37.93%
PENNSBURY TWP	113.98	43.48	61.85%
POCOPSON TWP	821.21	320.79	60.94%
SADSBURY TWP	289.73	172.13	40.59%
THORNBURY TWP	82.17	34.46	58.06%
VALLEY TWP	485.14	164.64	66.06%
WALLACE TWP	21.74	17.41	19.92%
WEST BRADFORD TWP	283.22	121.60	57.07%
WEST CALN TWP	68.28	43.07	36.92%
WEST GOSHEN TWP	461.32	180.51	60.87%

Table 4-9. Average annual sediment allocations for towns in Red Clay Creek Watershed

Township	Baseline (ton/yr)	TMDL (ton/yr)	Percent Reduction
EAST MARLBOROUGH TWP	8791.41	4193.24	52.30%
KENNETT SQUARE BORO	840.10	405.41	51.74%
KENNETT TWP	6751.63	3312.06	50.94%
NEW GARDEN TWP	4709.65	2118.72	55.01%

Table 4-10. Average annual sediment allocations for towns in White Clay Creek Watershed

Township	Baseline (ton/yr)	TMDL (ton/yr)	Percent Reduction
AVONDALE BORO	463.65	140.02	69.80%
FRANKLIN TWP	4220.43	2305.87	45.36%
LONDON BRITAIN TWP	2634.66	1620.44	38.50%
LONDON GROVE TWP	13616.33	4842.81	64.43%
NEW GARDEN TWP	6746.50	2986.66	55.73%
NEW LONDON TWP	1913.97	1008.60	47.30%
PENN TWP	3584.76	1410.29	60.66%
WEST GROVE BORO	562.29	192.63	65.74%

4.2.6 Critical Conditions

The HSPF model is a continuous-simulation model that uses daily time steps for weather data and water balance calculations. The average annual yearly calculations made for the sediment loads shown in the average annual TMDL allocation tables in the previous section were based on the daily model simulation output and summed to get yearly values. Therefore, all flow conditions are taken into account for loading calculations. Because there is usually a significant lag time between the introduction of sediment to a waterbody and the resulting impact on beneficial uses, establishing these TMDLs using average annual loads is protective of the waterbody.

4.2.7 Seasonal Variation

The continuous-simulation model used for this analysis considers seasonal variation through a number of mechanisms. Daily time steps are used for weather data and water balance calculations. The HSPF model had for a four-year period (October 1, 1994, through October 1, 1998). This period is characterized by both extreme low flows during the summers of 1995 and 1997, as well as high-flow events during storms. This simulation period covered the range of typical critical hydrological conditions expected in the Christina River Basin. The combination of these model features accounts for seasonal variability.

4.2.8 Margin of Safety

The CWA and Federal regulations require TMDLs to include a MOS to take into account any lack of knowledge concerning the relationship between effluent limitations and water quality. EPA guidance suggests two approaches to satisfy the MOS requirement. First, it can be met implicitly by using conservative model assumptions to develop the allocations. Alternately, it can be met explicitly by allocating a portion of the allowable load to the MOS. These TMDLs use an explicit five percent MOS.